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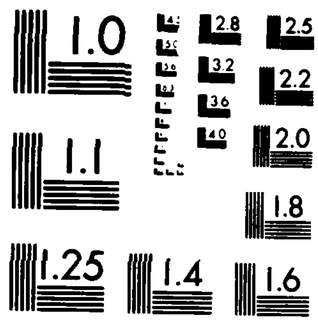

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ROCKET-BORNE POSITIVE AND NEUTRAL BEAM EXPERIMENTAL PLAN

J.W. Carpenter
C.H. Humphrey

Visidyne, Inc.
5 Corporate Place, S. Bedford Street
Burlington, MA 01803

Final Report for Period 1 July 1979 - 30 September 1982

Approved for public release; distribution unlimited

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this report the design of a rocket-borne charge ejection payload consisting of proton and neutral hydrogen beams is presented. The experimental plan calls for beams to be emitted up, down, and perpendicular to the geomagnetic field to be intercepted by throw-away detectors (TADS). This experimental plan is designed to be very cost effective, while extending the present upper limit of heavy charged beams to higher levels and revealing significant scientific information.

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Acknowledgement

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I. Introduction

This report describes a rocket-borne experiment to provide high energy (100 keV) proton and neutral hydrogen beams in space.

The objectives of this rocket experiment are:

a) To generate and propagate energetic positively charged and neutral heavy particle beams through space and into the atmosphere;

b) To propagate these beams through space for detection by remote target payloads (daughter vehicles);

c) To elucidate the charge-up behavior of the beam-source vehicle (mother payload);

d) To elucidate the charge-up behavior of the target payloads and any induced transient fields;

e) To determine the efficacy of discharge (i.e., simple neutralization) techniques to reduce the charge-up for the source and target vehicles;

f) To determine the degree of divergence, and nature of any instabilities, in the beams by mapping the beam profiles; and

g) To detect and identify any phenomenon analogous to beam plasma discharge for electrons.

In synopsis the experiment is envisaged as follows:

A mother payload will carry the accelerator, the neutralizer, diagnostic and housekeeping monitors to altitudes of about 300 km. The axis of the mother payload is oriented at right angles to the geomagnetic field. From the mother payload four daughter payloads, called Throw Away Detector Systems (TADS), are ejected: one up the magnetic field, one down the field and the other two orthogonal to the field and in opposite directions. The mother payload is then spun up to 2 or 3 revolutions per second and the pre-programmed modulated beam turned on. The beam vector being perpendicular to the axis of the mother payload, the beam will be emitted up the field out of the sensible atmosphere, down the field and be deposited far below the rocket and at right angles to the field and the beam profile mapped in each direction by the TADS.

The successful performance of this program will provide the first positive step toward the use of energetic heavy, particle beams in space. The objections raised to the use of heavy particle beams in space recall similar objections raised in the early planning days of the Hess-Winckler Echo and the Stair Excede experiments. Both of these experiments have been successful and have exceeded the, then-thought, critical maximum current levels by orders of magnitude.

Further, the experiments suggested here, using a mother-daughter approach, will permit the examination of charge-up and neutralization of a remote, essentially floating target and phenomenon analogous to the system-generated electromagnetic pulse (SGEMP) effects so worrisome in nuclear effects.

II. Accelerator

To ensure the chances of an early successful flight we would like to use an accelerator that has already proven itself in harsh environments and one that needs a minimal amount of development. Our candidate is a modified Kaman Sciences, Inc. well logger - the Zetatron. Table 1 provides a summary of some of the important characteristics of this device.

The high current pulse (0.07-0.1 amp) and short pulse duration (10 μsec) both work to our advantage in the charge-up and beam detection studies. The energy range (50-130 keV) is high enough to form a real advance in energetic heavy particle beams in space, high enough to permit efficient detection of the beam particles at the mother and daughter vehicles, high enough to provide a useful range through the ionosphere, and low enough to permit a relatively simple but efficient neutralization technique to be used.

Figure 1 presents a schematic of the ion-source (a Penning type) and the accelerator. It is seen that the overall length is about 5 inches and the diameter is about 1 1/2 inches. The basic cost (off-the-shelf) of this unit is about $13,000. It must be modified to remove the target assembly and replace it with an accelerating grid and focussing electrodes. A power supply to provide the required voltage and power and capable of operating in a rocket-borne space environment must be designed and tested. This requires no new technology as evidenced by a somewhat similar power supply flown by Winckler on the Echo Experiments (40 keV and 1 amp).

The particle accelerator power supply will probably be a high voltage, high-frequency step-up transformer driven by a solid state inverter. The drive frequency could be 50 khz. This could then provide a beam modulation pattern of 10 μsec on and 10 μsec off.

The transformed output would be 100 kV at 10 kW. The transformer should be no larger than about 4" X 4" X 8" and could be mounted in 12" diameter and 18" long cylinder filled with silicon oil to provide the required insulation from breakdown.

III. Beam Neutralizer

For protons in the 10 to 200 kilovolt energy range a relatively simply charge exchange or neutralization system can be used to produce a neutral beam of hydrogen atoms from the proton beam. Figure 2 shows the electron capture cross section σ_{10} for protons in molecular nitrogen. The reaction is

$$H^+ + N_2 \text{ (ground)} \rightarrow \Sigma\, H(ml) + \Sigma N_2^+ \qquad (3.1)$$

TABLE 1. ZETATRON*

(Produced by Kaman Sciences, Inc.)

- Pulsed Proton Accelerator
- Single Column DC Voltage Generator
    - 50-130 keV
    - 0.07-0.1 amp/Pulse
    - 10×10^{-6} Sec Pulse Length
    - <20 lbs
    - 0.02 ft^3 (Accelerator Only)
    - 0.13 Joules/Pulse
    - ~$13,000 Cost**

*Data from Halverson, W., and S.N. Bunker. Definition Study of High-Energy Accelerator Systems for Applications in Space, Final Report F19628-81-C-0102, AFGL. To be published.

**Basic off-the-shelf cost prior to development for rocket flight.

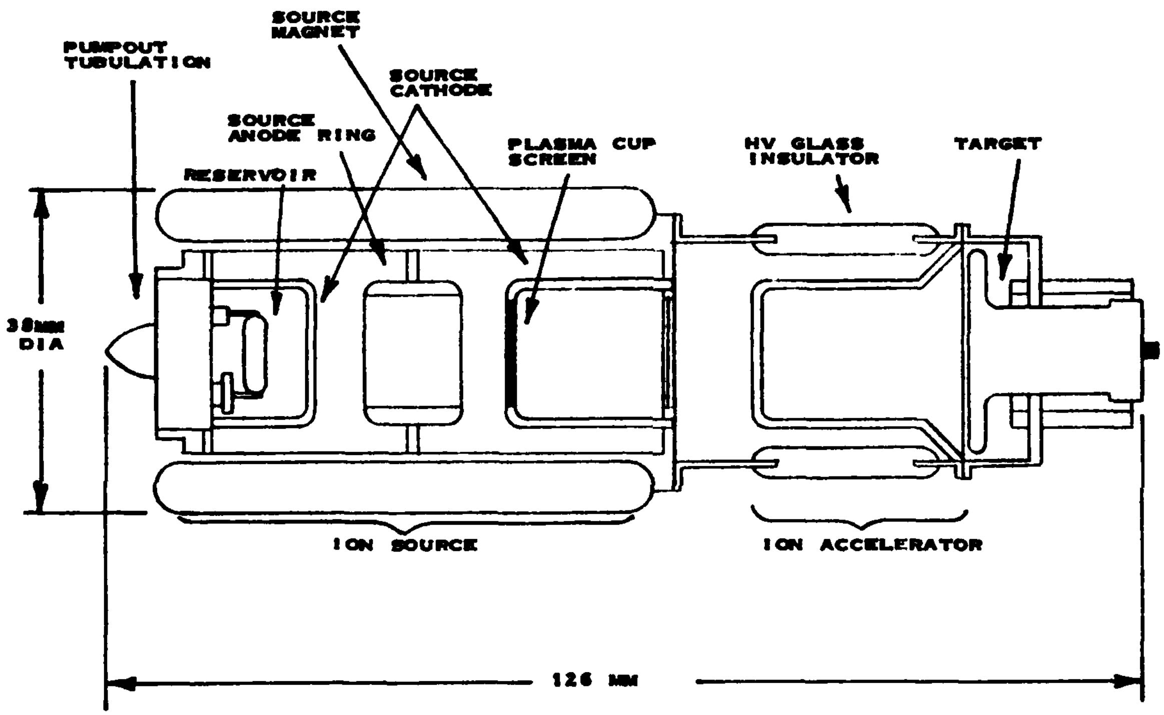

Figure 1. Zetatron Accelerator

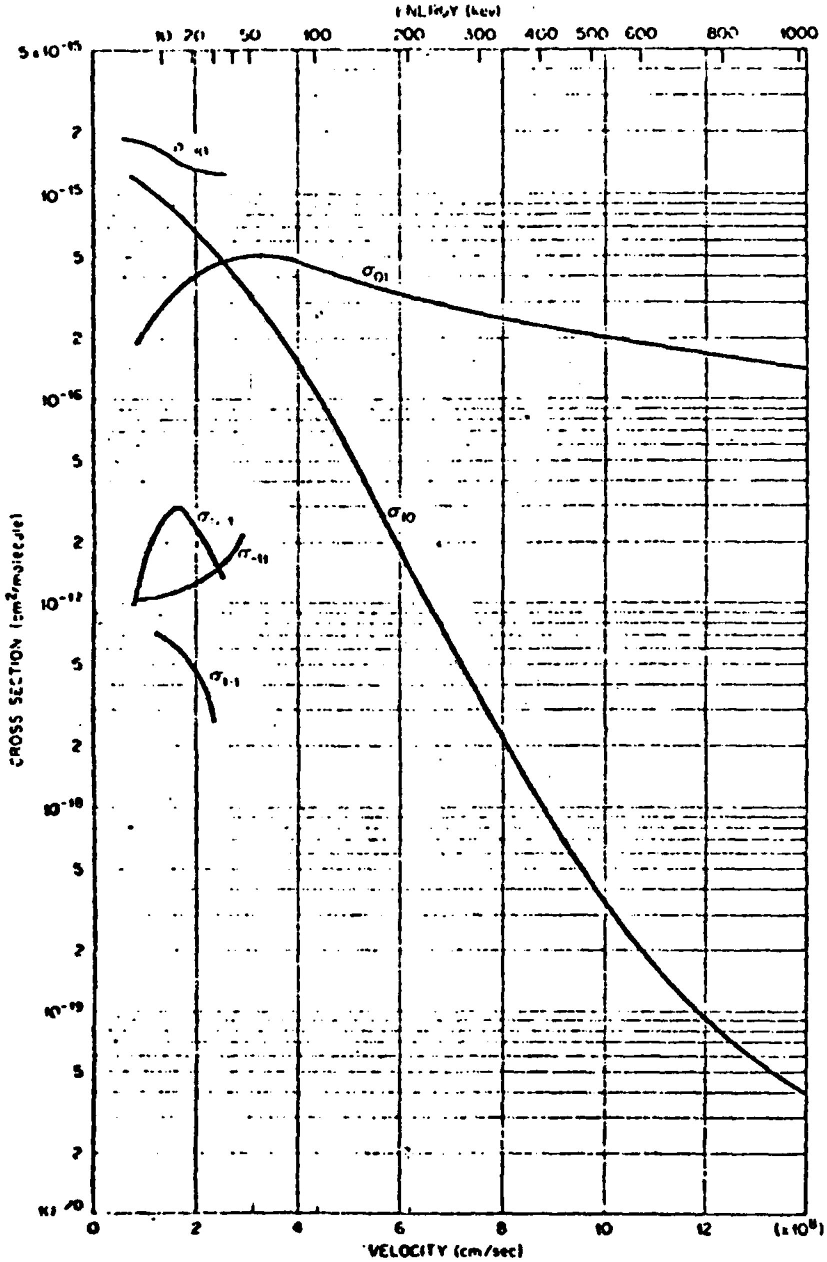

Figure 2. Charge transfer cross sections of Hydrogen atoms and ions in Nitrogen gas.

It is a strong function of energy in this non-relativistic regime. Near 100 keV a fit to the cross section demonstrates this and is given approximately by

$$\sigma_{10} = 1.1 \times 10^{-16} \, (100/E(\mathrm{keV}))^{2.78} \mathrm{cm}^2 \quad (3.2)$$

Conceptually we view the charge exchange (i.e., the neutralization or electron capture) system as consisting of a flask of volume $V_f(\mathrm{cm}^3)$, filled with nitrogen at pressure P (psia) and temperature T(K), whose nozzle is designed to allow the proton beam to fire down the axis of the nozzle. (See Figure 3).

For calculational purposes, we denote the coordinate along the beam as z, the half angle of the nitrogen jet as θ, the location of the nozzle entrance at a distance z_o from the virtual apex of the cone, and $n(z)$ as the nitrogen density at any point z along the neutralizer.

The concentration of neutral hydrogen atoms along the beam is then given by

$$\frac{d[H^o]}{dz} = -\sigma_{01} n(z)[H^o] + \sigma_{10} n(z)[H^+] \quad (3.3)$$

where $\sigma_{01} = 4.3 \times 10^{-16} \mathrm{cm}^2$/molecule at 100 kev is the ionization cross section (See Fig. 2)

$\sigma_{10} = 1.1 \times 10^{-16} \mathrm{cm}^2$/molecule at 100 kev is the de-ionization cross section, and

$[H^+]$ is the proton concentration in the proton beam.

By conservation of particles we have

$$[H^+] + [H^o] = [H^+]_o \quad (3.4)$$

where $[H^+]_o$ is the initial beam concentration when it enters the neutralizer. Substituting Eq. 3.4 in Eq. 3.3 the neutral concentration can be written as

$$\frac{d[H^o]}{dz} = -\sigma_{01} n(z)[H^o] + \sigma_{10} n(z)[H^+]_o - \sigma_{10} n(z)[H^o]$$

or

$$\frac{d[H^o]}{dz} = -\sigma_T n(z)[H^o] + \sigma_{10} n(z)[H^+]_o \quad (3.5)$$

$$\text{where } \sigma_T = \sigma_{10} + \sigma_{01} \quad (3.6)$$

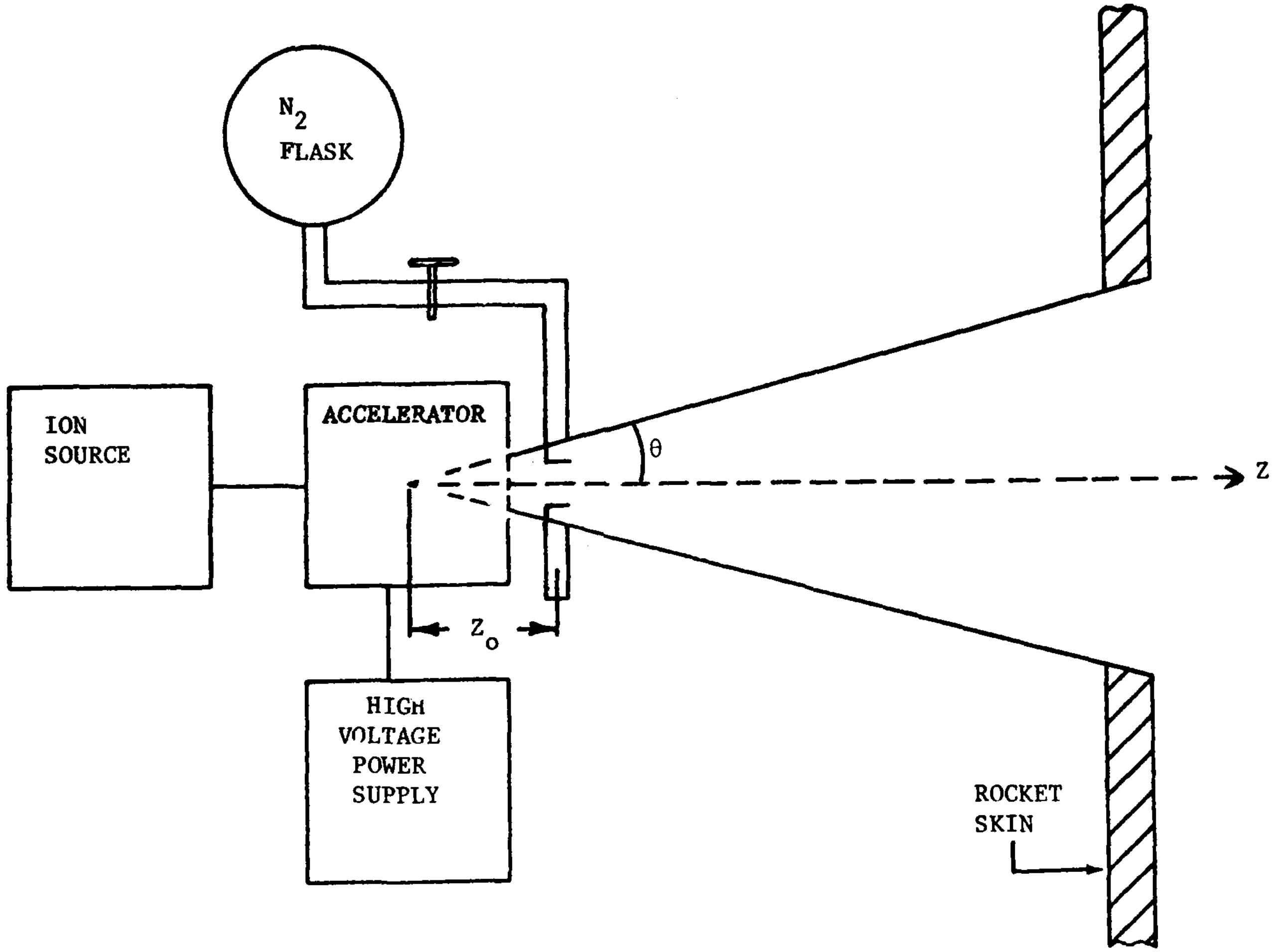

Figure 3. Beam neutralizer schematic.

If the flow rate of neutralizing nitrogen out of the flask is Q(t) (molecules/sec), the molecular concentration in the neutralizer is then

$$n(z,t) = \frac{Q(t)}{dVol}\,dt = \frac{Q(t)dz/v_z}{\pi z^2 \tan^2\theta dz} = \frac{Q(t)}{\pi v_z z^2 \tan^2\theta} \tag{3.7}$$

or $n(z,t) = n_o(t)(z_o/z)^2$ (3.8)

where $n_o(t) = \dfrac{Q(t)}{\pi v_z z_o^2 \tan^2\theta}$ (3.9)

The solution of Eq. 3.5 is then

$$f_n = \frac{[H^o]}{[H^+]_o} = \frac{\sigma_{10}}{\sigma_T}\left[1 - \exp(-\sigma_T n_o z_o(1 - z_o/z))\right] \tag{3.10}$$

where f_n is the fraction of the beam neutralized as a function of time (implicit in $n_o(t)$) and distance along the beam.

For z much greater than z_o, the fraction of the beam neutralized approaches the limit

$$f_n \approx \frac{\sigma_{10}}{\sigma_T}\left[1 - \exp(-\sigma_T n_o z_o)\right] \tag{3.11}$$

If we choose to take the initial value of the exponential term to be 0.1, or less,

$$\sigma_T n_o z_o \geq 2.303 \tag{3.12}$$

Under the conditions of $\sigma_T n_o z_o = 2.303$ then

$$f_n = \frac{1.1}{5.4}[1 - 0.1] = \frac{0.9 \times 1.1}{5.4} = 0.18$$

of about 18% of the beam is neutralized at a proton beam energy of 100 keV.

To determine the size flask needed and the pressurization required, consider first the velocity of escape through a nozzle in the flask. This is given by

$$v_z = \sqrt{8kTL/\pi A} = 4.76 \times 10^4 \text{cm/sec} \tag{3.13}$$

where L is Avogadro's number (6.02×10^{23})

A is gram mol.. ..ular weight of nitrogen (28)

T is the temperature (300K)

and k is the Boltzmann constant (1.4×10^{-16} ergs/K)

If N(t) is the total number of molecules in the flask at a time t then the decrease in N is given by

$$\frac{dN}{dt} = -\frac{1}{4}\frac{N}{V_f} v_z A_o \tag{3.14}$$

where A_o is the nozzle aperture and V_f is the flask volume. Hence, if the initial number of molecules is N_o then

$$N(t) = N_o \exp(-v_z A_o t/4\ V_f) = N_o e^{-t/\tau} \tag{3.15}$$

where the e-folding time τ is

$$\tau = 4\ V_f/v_z A_o \tag{3.16}$$

The flow rate Q(t) is related to the number of molecules in the flask by

$$Q(t) = N(t) v_z A_o/V_f \tag{3.17}$$

Combining Eq.'s 3.17, 3.15, 3.12 and 3.9 we find

$$N(t) \geq \frac{2.303\pi\ V_f z_o \tan^2\theta}{A_o \sigma_T} \tag{3.18}$$

or

$$N_o \geq \frac{2.303\pi\ V_f z_o \tan^2\theta\ e^{t_f/\tau}}{A_o \sigma_T}$$

where t_f is the required time of extent of the release of the neutralizing gas.

To define a sample case let us choose the following values:

$V_f = 1$ liter $= 10^3 cm^3$ $\quad$ T = 300K

$z_o = 10$ cm $\quad$ $\theta = 0.1$ rad

Table 2 gives, for various values of A_o and t_f, the initial value of N_o required, the initial pressure in the flask that this corresponds to, the required $N(t_f)$ to just satisfy our requirements and how this compares with the value of $N(t_f)$ for a pressure of 10^3 psi.

It is seen, for example, that for an experiment time of continuous discharge for 420 seconds through an aperture of $10^{-3}cm^2$, sufficient gas would be carried in this one liter flask at a pressure of 117 psi. At 10^3 psi there would be a safety margin of almost a factor of ten after 420 seconds of operation.

Hence, using a reasonable gas source, namely a one liter flask of nitrogen at 1000 psi, about 20% of the proton beam can be neutralized for experiment periods of 400 to 800 seconds of continuous operation.

The use of a preprogrammed modulation of the value of the nitrogen flask would allow the alternate use of a pure energetic proton beam and mixed proton and neutral hydrogen beams. The propagation behavior across the geomagnetic field can, with the increasing separation distance between the mother-daughter payloads, be used to differentiate between the mixed beams.

IV. Beam Propagation

Protons ejected perpendicular to the geomagnetic field will describe a circular path whose gyroradius is given by

$$R_g = \frac{M_H c}{eB} \sqrt{T}$$

where T is the normalized kinetic energy given by

$$T = \frac{M_H v^2}{2M_H c^2}$$

For example, for regions where the magnetic field strength is about 0.4 gauss and for 100 keV protons, the gyroradius is R_g = 780 meters.

Protons ejected along the magnetic field toward the TADS will be detected at any distance, as will the hydrogen beam produced where the protons have been neutralized. For those TADS ejected at right angles to the field, once the TADS have drifted about 2 R_g away the proton beam will no longer reach them but the neutral beam will continue to do so. Thus, the earth's magnetic field can be used to discriminate the charged and neutral beams.

Figure 4 presents the range-energy curves for energetic protons (as well as other particles) in a number of media including air. From this we see that the integrated range at 100 keV energy in the atmosphere is about $2 \times 10^{-4} g/cm^2$. For protons fired into the atmosphere along the magnetic field at a dip angle of 60^o, they will deposit over a scale height at an altitude no deeper than about

TABLE 2. REQUIRED FLASK PRESSURE

$A_o(cm^2)$	$t_f(s)$	τ	$N_o$min	P(psi)*	$N_o e^{-t_f/\tau}$	$N(t_f)$**
10^{-4}	840	840	3.57(22)	21.5	1.31(22)	6.11(23)
$3x10^{-4}$	840	280	8.80(22)	53.0	4.38(21)	8.27(22)
10^{-3}	420	84	1.95(23)	117.0	1.31(21)	1.12(22)
10^{-3}	840	84	2.90(25)	$1.75x10^4$	1.32(21)	7.50(19)

**Flask Pressure 10^3 psi

* at STP 1 liter contains 2.68×10^{22} molecules

at 300K 1 liter contains 2.44×10^{22} molecules

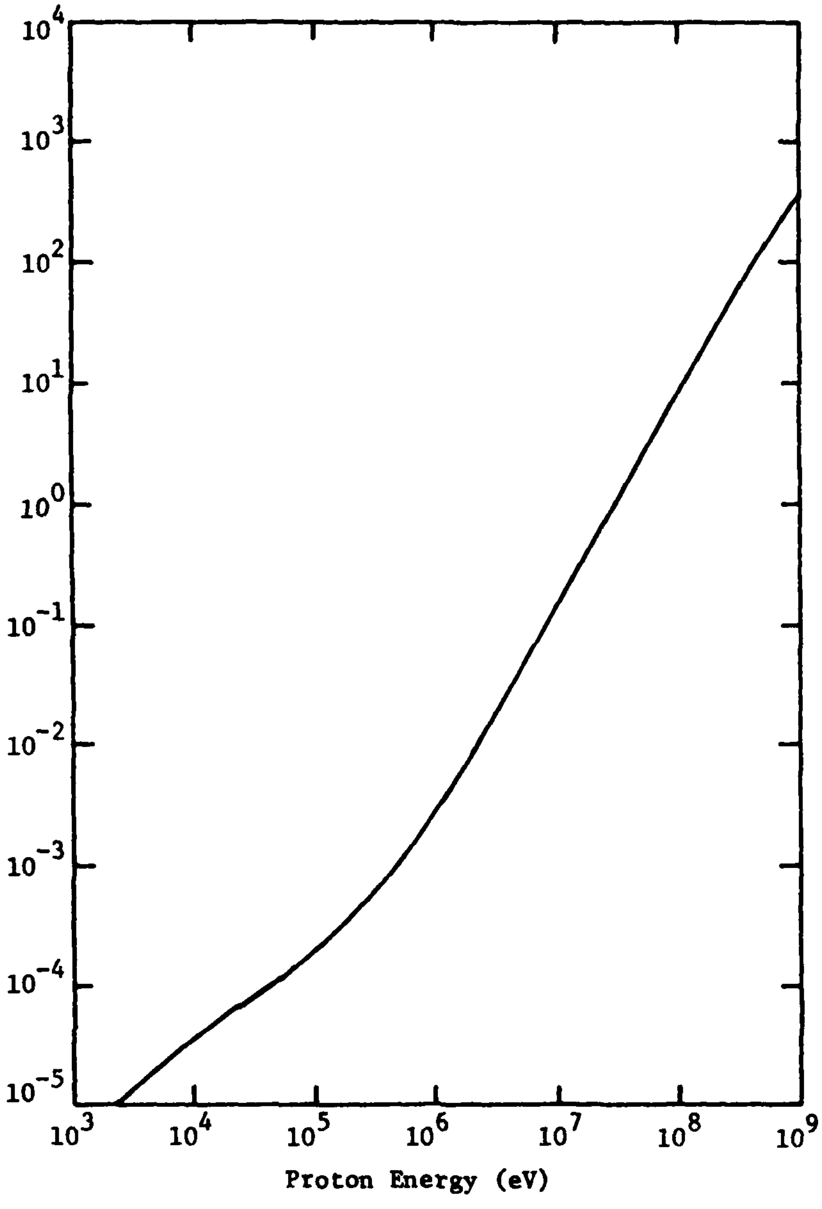

Figure 4. Proton range - energy curves in air.

103 km. Here the scale height, H, is almost exactly 6 km so the maximum volume of deposition is

$$Vol_{max} = \pi R_g^2 H$$

and the maximum brightness through the axis of this volume is

$$F_\lambda = \frac{2K\ IV\eta_\lambda R_g}{Vol_{max}(hc/\lambda)}$$

where I is the beam current

V is the beam voltage

λ is the fluorescent emission wavelength

η_λ is the fluorescent efficiency and

K is the proportionality coefficient from photons/cm^2 column sec to kilo Rayleighs (10^{-9})

Considering the brightness of the near ultraviolet emissions, namely, that of the N_2^+ First Negative 0-0 transition at 3914A, we take the fluorescent efficiency to 1/2%, the photon energy to be about 3.2 ev, the beam current to be 0.1 amp and the beam voltage to be 100 keV, then the minimum brightness is

$$F_{3914} \leq 1.4 \text{ kR}$$

which should be readily recordable through a low light level television system.

The neutral hydrogen beam particles have the same range in air as protons of the same energy. Consequently, the beam will, when directed downward, penetrate as deeply but will be unaffected by the magnetic field until charge exchange or ionization occurs. Therefore, the beam deposition may have a somewhat larger volume with a proportional decrease in column brightness.

V. Payload Charge-Up and Neutralization

The mother payload which carries the accelerator will tend to charge-up to a negative potential that is off-set in part by the surrounding natural ionosphere and any local ionization produced by the beam. However, due to the low mobility of the surrounding air ions the vehicle can, in principle, charge-up to relatively high potentials. For example, the air ion mobility doesn't become equal to that of the electrons until voltages of over a kilovolt are attained. Further, if the skin of the mother vehicle is almost completely coated with a non-conductor so that the collecting area for ions is greatly reduced, then the vehicle potential can be driven up to higher values than would otherwise be attainable.

To discharge the mother vehicle a low energy electron gun capable of 100 mamps at about one kilovolt should prove sufficient. The energy of one kilovolt is needed to allow sufficient current to be extracted easily. This gun should be able to be preprogrammed to allow the effects of charge-up of the mother vehicle on the proton and neutral beams to be studied as well as effects due to any internal discharges due to the self fields generated.

The daughter vehicles will experience transient charging and discharging as the proton beam sweeps by. Due to the spin rate of the ion source and dynamics, the beam will illuminate the daughter vehicle for only about 16 milliseconds every 500 milliseconds. (See Section 6.2).

Assuming that the mother-daughters separate at some 10 meters/second and assuming that the accelerator is turned on two seconds after separation, the maximum charge imparted to the daughter vehicle per-pulse at a time t after separation is given by

$$\Delta Q(t) = \frac{I_b D \Delta t_b A_1}{\pi(\theta)^2 (v_s t)^2}$$

where A_1 is the projected area of the daughter normal to the beam (m^2),

I_b is the beam current (0.1 amp),

D is the duty cycle of the beam (0.50),

θ is the half angle of the beam (0.1 rad),

v_s is the velocity of separation (10 m/sec),

t is the time after separation (sec), and

Δt_b is the period of illumination of the daughter vehicle by the beam and is given by

$$\Delta t_b = \frac{2\theta}{2\pi} \times \frac{1}{f}$$

where f is the rocket spin frequency (2 rps).

For our hypothetical daughter vehicle which is a cylinder that is 6 inches in diameter by 12 inches in length and whose spin is such that a base always faces the mother payload, that projected area is $A_1 \approx 0.018\ m^2$.

The effective capacitance of the daughter payload can be estimated by sphericalizing it. That is the effective radius is

$$R_{eff} \approx \frac{0.0254}{2} (6 \times 6 \times 12)^{1/3} \text{ meters}$$

and the effective capacitance is

$$C_{eff} = 4\pi\varepsilon o\ R_{eff} = 1.06 \times 10^{-11} \text{ farads}$$

Therefore the maximum voltage rise the daughter payload could experience per pulse, if it were in a vacuum, would be

$$\Delta V(t) = \Delta Q(t)/C_{eff}$$

$$\Delta V(t) = \frac{I_b D A_1}{\pi^2 \theta\ f(v_s t)^2} \ \frac{1}{4\pi\varepsilon_o R_{eff}} = 4.6 \times 10^5/t^2 \text{ volt/pulse}$$

(Figure 5 presents the voltage rise/pulse as a function of time after separation and distance of separation).

Since the daughter payload is in the ionosphere and some additional ionization is produced by the passage of the proton beam and/or neutral beam, the daughter can discharge between pulses to an extent that will be determined largely by the altitude and separation of the payloads, and the dosing rate.

VI. Diagnostics

6.1 Mother Payload

The usual on-board diagnostics are required to monitor the behavior of the accelerator system. These are designated in Table 3 as beam voltage and beam current monitors, return current monitors to various portions of the mother payload skin as well as battery and high voltage power supply monitors. The low energy electron accelerator is likewise monitored as to voltage current, as well as the normal housekeeping chores. The neutralizer gas flow and valving is to be monitored, as well as the payload orientation through the use of a three-axis magnetometer and monitoring of the ACS.

The beam interaction with the atmosphere and its dimensions and shape is to be monitored on-board the visible light photometers filtered to 3914A and the hydrogen H_α line.

6.2 Daughter (Target) Payloads

Four daughter payloads, that is, the TADS, ejected as indicated earlier, one up and one down the magnetic field line and two normal to the magnetic field, will contain return current monitors to determine charge-up and discharge conditions probably using an electrometer.

The proton beam (and the neutral beam when the neutralizer is operating) would be monitored by a pair of small autonomous detector packages on the TADS. Each package would contain two complementary solid-state proton detectors, associated electronics and power supplies.

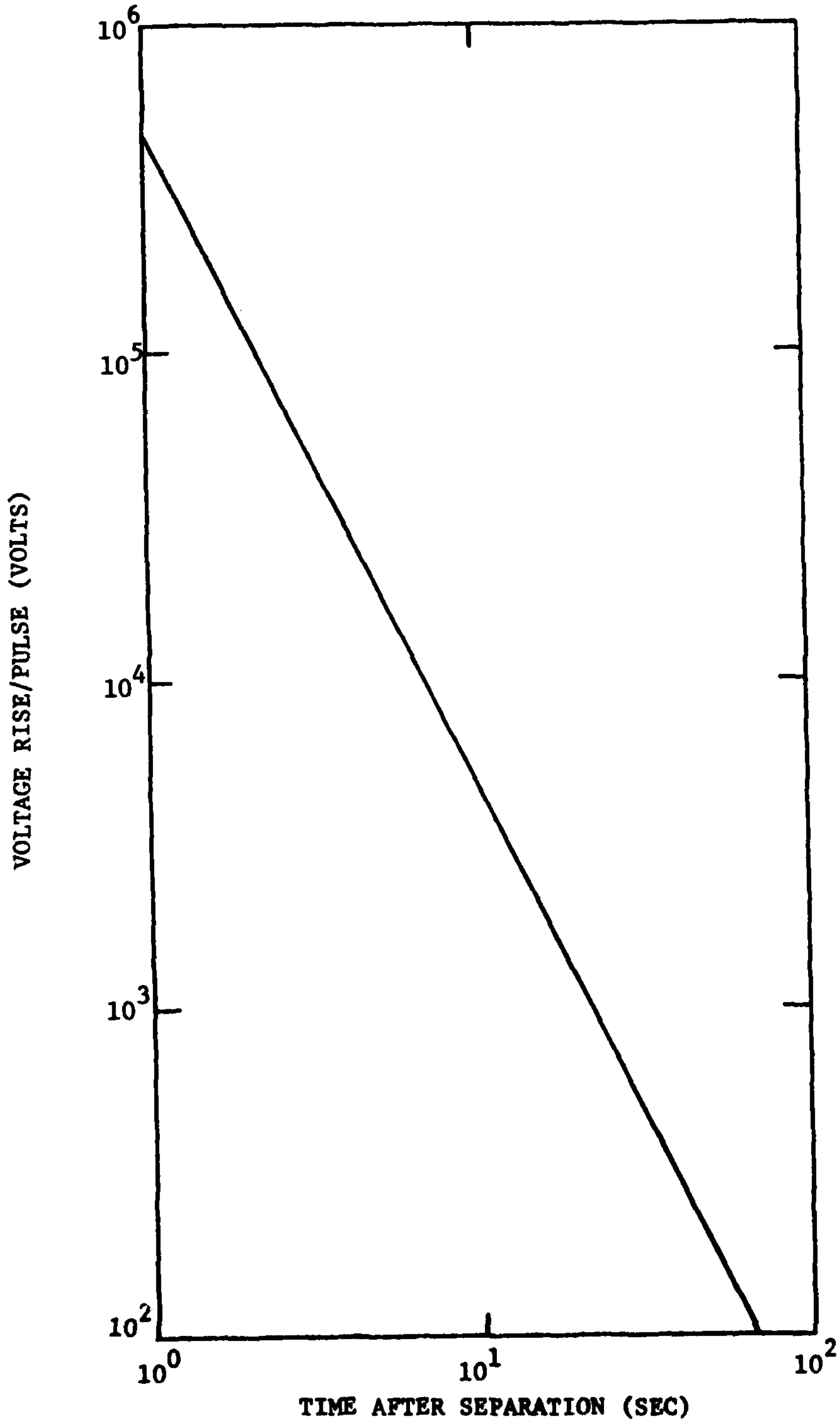

Figure 5. Voltage rise per pulse versus time after separation.

TABLE 3. ACCELERATOR PAYLOAD DIAGNOSTIC

Ion Accelerator	Beam Neutralizer	Electron Accelerator
Ion Source	Neutralizer Gas Pressure	Filament Voltage
Filament Voltage	Neutralizer Valve Position	Filament Current
Ion Source Current	Magnetometer	Pulse Voltage Monitor
Pulse Voltage Monitor	ACS Readout	Pulse Current Monitor
Pulse Current Monitor		Battery Voltage Monitor
Interception Current Monitor		Battery Current Monitor
Return Current Monitor		Temperature Monitors
Stage Voltage Monitor		Accelerator Cover Monitor
Battery Voltage Monitor		**Experiment Diagnostics**
Battery Current Monitor		Vehicle Potential (RPA - slow)
Trigger Pulse Monitor		Fast Rise Vehicle Potential
Beam Source Pressure Monitor		Return Current (high energy particles)
Ambient Pressure Monitor		Ambient Plasma (low energy particles) On Skin
SF_6 Pressure Monitor		Near Field Interactions (optical)
Various Temperature Monitors		E-Field
Vac Ion Pump Current Monitor		Ambient Plasma
Accelerator Cover Ejection Monitor		RF
Various Low Voltage Monitors		X-rays
		Size of Plasma Sheath
		Depth of Penetration
		Shape of Beam

These particle detectors would be solid-state surface barrier devices which operate near room temperature with modest bias voltages of a few hundred volts. One detector would have an active area of about 1 cm^2 while the complementary detector would have an area of about 3 mm^2 to provide for a larger dynamic range of detectable proton or neutral hydrogen fluxes. The actual detectors are extremely compact, occupying a volume of about 20 cm^3 and weighing less than 100 grams each. Adequate high-voltage supplies for powering the detectors are available in extremely modest sizes and weights. In order for a proton to be detected it must first pass through a gold contact layer (~40 μg cm^{-2}) as well as a dead layer of Si (~800 Å thickness). Protons with energies of ~100 keV will lose less than 20% of their initial energy in these dead layers before being detected. The charge collected by the detector is roughly proportional to the residual energy of the proton, with a conversion factor of ~3.5 eV per hole-electron pair.

It is anticipated that the mother payload containing the accelerator will be rotating at a rate of about 2 rps. Because the particle beams will be ejected in a beam with a full width of about 12°, each detector package will be illuminated by the beam for about 1/30 of a rotation cycle or about 15 msec. The proton gun is expected to have a pulse duration of ~10 μsec with a repetition interval of perhaps 10 to 50 μsec. Each proton pulse should yield a flux of $2 \times 10^8/t^2$ proton/cm^2 at a time t after separation. The neutral hydrogen beam flux should be about one-fifth of the proton flux. The larger-area detector will thus receive a deposited energy of $2 \times 10^8 \times 0.8 \times 10^5/t^2 = 1.6 \times 10^{13}/t^2$ ev per pulse; the corresponding energy collected by the smaller detector is about 1/30 that of the larger detector.

The electronics for each detector would be designed to integrate the charge collected over a ~10 μsec interval, and subsequently convert the signal to a digital number which can be temporarily stored. After recording and summing the total charge from pulses covering an interval of 1/4 msec, the corresponding digital value would be telemetered to the ground as a 10 bit number. This type of measurement can yield proton flux determinations with accuracies of up to 0.1% (at the higher fluxes) and can cover a dynamic range of ~10^4:1 in intensity by using both the small and large detectors. The angular resolution with which the proton beam can be probed is about 12 minutes of arc or 64 samples across the beam. The required telemetry rate is 80 kbits s^{-1}.

A possible telemetry system for one of the TAD modules is summarized in Table 4. This design is based upon the requirement to transmit real time sensor data from each TAD to a ground station at ranges of up to 400 km. A 5 watt transmitter has been selected, but this could be increased to 8 watts if necessary, with a small weight increase.

Antennas have been flown on similar modules having random aspect (see the AFGL Falling Sphere Experiments) and if the length/diameter ratios of the TAD is small, then it may be possible to use a similar unit. The PCM encoder is a standard lightweight programmable which provides IRIG compatible PCM data. The battery will consist of sealed NiCd cells having 1 amp hour capacity permitting 1/2 hour of continuous transmitter operation.

TABLE 4. TELEMETRY SYSTEM FOR TAD

Component	Designation	Weight (lb)
Antenna	To Be Designed	2 (est)
Antenna	Loral CTS70S	1
PCM Encoder	Loral PCM440	0.8
Battery	1 AmpHr NiCd	3.5
Cables & Mounting		2
	TOTAL WEIGHT	9.3 lbs

Figure 6 presents a schematic layout of the target payload. The 12 inch length may be shortened a little but overall it will fit quite well within the 18 inch diameter of the rocket payload.

6.3 Ground-Based Instrumentation

A 10 kw accelerator for the rocket payload is proposed here. To detect the interaction of the proton or neutral beam produced by this accelerator with the atmosphere from the ground we suggest the use of a low light level television camera (LLTV) and a coaligned telephotometer filtered to the 3914A N_2^+ First Negative Band. This combination was used quite successfully on the Excede II Test Flight where the beams from two 15 kw electron accelerators (not always fired simultaneously) were monitored from turn-on to apogee at about 135 km altitude. Hence, the 10 kw proton beam should be distinguishable above background for a reasonable portion of the flight, especially when pointed into the atmosphere along the magnetic field.

Consideration should be given, perhaps, to monitoring the H_α radiation from the beam depositing in air.

VII. Payload and Trajectory

7.1 Accelerator Payload

A schematic representation of the mother vehicle is given in Figure 7. This payload consists of a nominal 100 keV, 0.1 amp pulsed proton accelerator with its associated power supply and batteries. A nitrogen supply flask and controller are to provide a neutral hydrogen beam during preprogrammed portions of the flight. The aforementioned diagnostics for accelerator behavior, flight characteristics of the payload, and on-board monitoring of the emitted beams are also carried. A recovery package is desirable. The accelerator is pointed out the side of the payload with the beam perpendicular to the long axis of the mother payload.

An Attitude Control System is used, together with a magnetometer, to orient the payload axis orthogonal to the geomagnetic field. After this has been accomplished and after ejection of the TADS at some 10 meters/sec, the mother payload is spun up to about 2 to 3 rps.

The mother payload specifications are given in Table 5.

7.2 Detector Payloads (TADS)

In addition to the mother payload, it would be desirable to carry four throw-away detector packages (TADS). Each of these packages uses the same telemetry system as the mother payload, namely 80 kbits/sec at 5 watts power. Table 6 gives the specification of these payloads. They are spun upon before launch and ejected so that the spin axis which is parallel to the long axis of the cylinder always points at the mother payload. The detectors are located in the face that always points toward the accelerator.

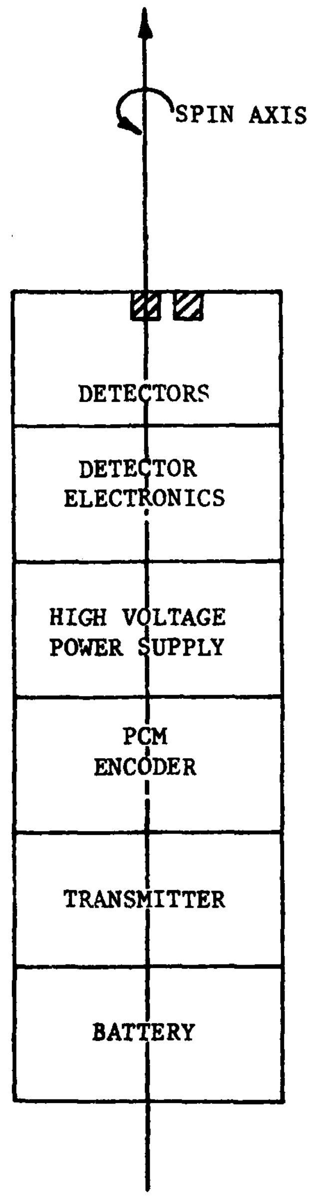

Figure 6. Throw away detector system (TADS) schematic.

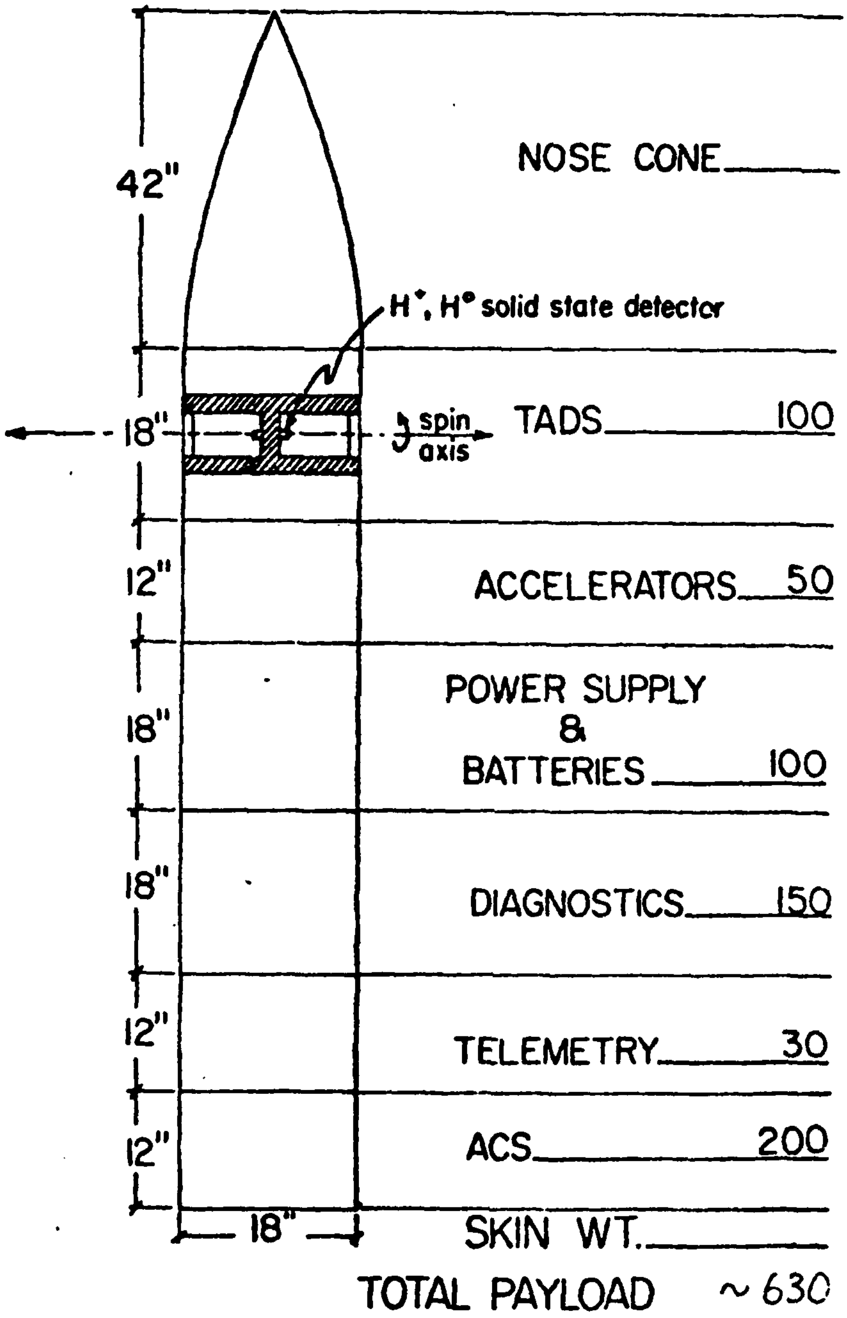

Figure 7. Rocket booster: Nike Black Brant.

TABLE 5. MOTHER PACKAGE

ACCELERATOR	- Zetatron modified for neutralization
	- 100 keV, 100 ma, 6^{o}(0.1 rad) beam half angle pulse rate - 5 X 10^{4} pulse/sec, 10 μsec pulses
SCENARIO	- TADs ejected at ~150 km
	- Spun (3 rps) so beam fires up/dn field

TABLE 6. DAUGHTER PACKAGE

NO.	- 4
SIZE	- 6" X 12"
WT	- 12 - 15#
SCENARIO	- Ejected at ~150 km
	- Spun (2 rps) along long axis
	- 1 up field, 1 dn field, 2 at rt angles
	- Separation velocity 10 m/sec
	- Separation distance 3 km @ 300 sec
DETECTOR	- 1 cm^2 on end facing mother
	- 10 Å gold film (10% absorption)

7.3 Trajectory and Orientation

As noted the mother payload is oriented by the ACS so that the spin axis is perpendicular to the geomagnetic field. The trajectory is determined by the required payload weight which from our estimates here should permit an apogee of over 300 km if a Nike-Black Brant rocket is used. Three examples of the payload weight and altitude time-histories are given in Figure 8.

The TADS as noted are to be ejected up and one down along the magnetic field line and two at right angles to the magnetic field.

7.4 Launch Site

Taking into account the desire for and wase of recovery, the White Sands Missile Range (WSMR) seems to be the most optimum of the potential launch sites - Wallops, Poker Flat, or Barking Sands, Kauai. This site is also economical from a logistical and launch support viewpoint, especially compared to Barking Sands. Either a North-South or South-North launch is acceptable. For the former the early part of the flight is tangent to the magnetic field and hence the fluorescent deposition stripe will tend to remain more stationary in the sky and nearer to the launch complex than would that for a South-North flight. A North-South launch is possible out of WSMR and was done of the PRECEDE I flight and monitored from Cloud Croft, New Mexico.

VIII. Estimated Costs and Schedule

Table 7 presents the estimated schedule to develop and test the accelerator, the TADS and the associated diagnostics. Apart from the low-level funding planning period, from inception to launch is only three years and the expenditure of \$2.5M. The largest portion of this expenditure (\$1.0M) is spent on accelerator development, testing and integration.

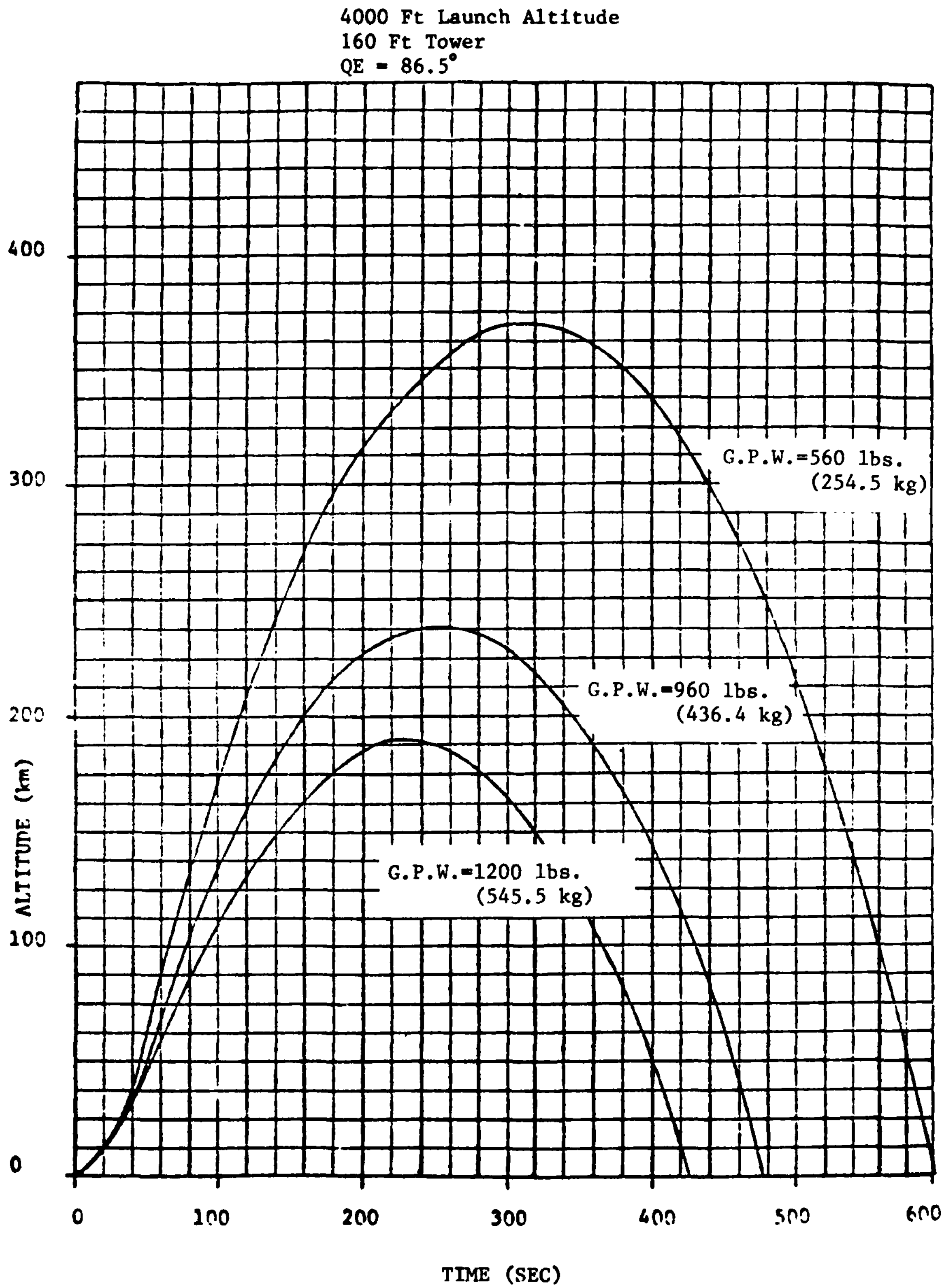

Figure 8. Altitude time histories versus payload weight for Nike-Black Brant rockets.

TABLE 7. ESTIMATED SCHEDULE AND COST

FY'84	'85	'86	'87	'88	'89	TOTAL
PLANNING AND THEORY	ACCELERATOR DEVELOPMENT	TESTING, SUPPORT, AND DIAGNOSTICS				
100K	500K	500K	500K			1,600K
	PLANNING AND THEORY	GROUND SUPPORT EQUIPMENT		DATA ANALYSIS	DATA ANALYSIS	
	100K	200K		300K	300K	900K
		ROCKET SUPPORT (LC)	ROCKET SUPPORT (LC)			
		200K	500K			700K
0.1M	0.6M	0.9M	1.0M	0.3M	0.3M	3.2M

$$R_{eff} \approx \frac{0.0254}{2} (6 \times 6 \times 12)^{1/3} \text{ meters}$$

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